Towards Electronic Shopping of Composite Product

Mark Sh. Levin

***Abstract*—In the paper, frameworks for electronic shopping of composite (modular) products are described: (a) multicriteria selection (product is considered as a whole system, it is a traditional approach), (b) combinatorial synthesis (composition) of the product from its components, (c) aggregation of the product from several selected products/prototypes. The following product model is examined: (i) general tree-like structure, (ii) set of system parts/components (leaf nodes), (iii) design alternatives (DAs) for each component, (iv) ordinal priorities for DAs, and (v) estimates of compatibility between DAs for different components. The combinatorial synthesis is realized as morphological design of a composite (modular) product or an extended composite product (e.g., product and support services as financial instruments). Here the solving process is based on Hierarchical Morphological Multicriteria Design (HMMD): (i) multicriteria selection of alternatives for system parts, (ii) composing the selected alternatives into a resultant combination (while taking into account ordinal quality of the alternatives above and their compatibility). The aggregation framework is based on consideration of aggregation procedures, for example: (i) addition procedure: design of a products substructure or an extended substructure ("kernel") and addition of elements, and (ii) design procedure: design of the composite solution based on all elements of product superstructure. Applied numerical examples (e.g., composite product, extended composite product, product repair plan, and product trajectory) illustrate the proposed approaches.**

***Index Terms*—Electronic shopping, modular products, morphological design, combinatorial optimization, multicriteria decision making, aggregation, customer centric design**

I. INTRODUCTION

In recent decade, the significance of electronic shopping and usage of corresponding recommender systems is increased (e.g., [13], [16], [27], [35], [39], [42], [44]). Here it is reasonable to point out the following basic directions: *1.* various recommender systems (e.g., [1], [4], [8], [18], [31], [34], [35], [45]); *2.* electronic services for business in electronic environments (e.g., [3], [5], [6], [25], [30], [39], [42], [46]); *3.* issues of distributed information retrieval and integration (e.g., [17], [37], [43]); *4.* multistage information retrieval (e.g., [33], [48]); *5.* design of websites for electronic shopping (e.g., [7], [44], [47]); *6.* usage of ontology approaches to web services (e.g., [36]); *7.* adaptation of Web sites and systems (e.g., [32]); *8.* personalization of Web-based systems (search and recommender systems, etc.) (e.g., [2], [8], [10], [33], [45]); *9.* usage of operations research methods and/or AI techniques (e.g., [12], [41]); and *10.* some efforts in Web-based product design, e.g., Web-based combining a composite product ([28], [40]), special designer-buyer-supplier interfaces over the Web to facilitate product development (e.g., [9], [14]). A simplified scheme 'user-electronic resources' is presented in Fig. 1. Note, the development of contemporary Web-based systems is targeted to and based on Web-based support systems (e.g., [27]). Decision support tools may be used at different levels: (i) interface, (ii) search engines, and (iii) data bases.

In our opinion, some basic problems in electronic shopping are the following (Table 1): (i) searching for a product on the basis of requirements (criteria) or user preferences, (ii) selection of a product on the basis of multicriteria decision making, and (iii) selection of product(s) under some constraints (e.g., multicriteria knapsack problem), (iv) multiple selection in several databases under a total resource constraint(s) (multiple choice knapsack problem), (v) design of a configuration for a modular product (e.g., morphological composition of the product from its components), and (vi) aggregation of selected modular solutions (as consensus, median-like solution).

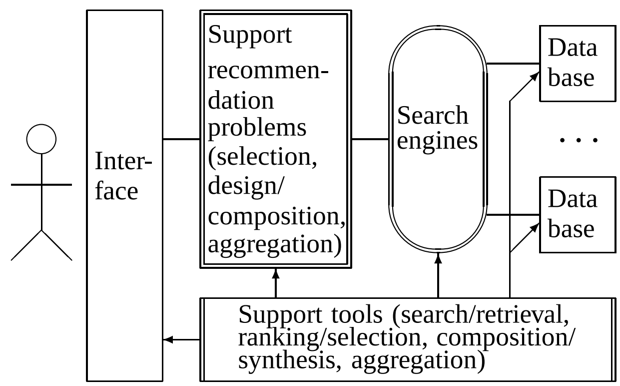

Fig. 1. General framework

Table 1. Problems and methods

Problems	Models/methods
1.Searching for a product	Information retrieval
2.Multicriteria selection of a product	Multicriteria ranking
3.Selection of products under resource constraint(s)	Knapsack-like problems
4.Multi-selection of several products under resource constraint(s)	Multiple choice problem (including multicriteria multiple choice problem)
5.Design of configuration for composite (modular) product, extended product	Morphological design, multiple choice problem, AI techniques, etc.
6.Aggregation of several selected products	Aggregation methods (e.g., consensus, median structure, new design)

This paper describes three basic frameworks for electronic shopping of composite (modular) products: *1.* multicriteria selection (product is considered as a whole system, it is a

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traditional approach); *2.* combinatorial synthesis (composition) of the product from its components (i.e., design/synthesis of configuration for the modular product and extended modular product); and *3.* design of an aggregated product on the basis of several selected products/prototypes.

The following model of the composite (modular) product is examined: ([19], [20], [21], [23]): (i) tree-like system structure, (ii) set of leaf nodes as system parts/components, (iii) design alternatives (DAs) for each system part/component, (iv) ordinal priorities for DAs, and (v) estimates of compatibility between DAs for different system parts/components.

Our combinatorial synthesis is based on morphological design of the composite (modular) product or extended composite product (e.g., product and support services as financial instruments). Here Hierarchical Morphological Multicriteria Design (HMMD) approach is used ([19], [20], [21]): (i) multicriteria selection of alternatives for system parts, (ii) composing the selected alternatives into a resultant combination (while taking into account ordinal quality of the alternatives above and their compatibility).

In this paper, two aggregation procedures are considered [23]: (i) addition (extension) procedure: design of a products substructure or an extended substructure ("kernel") and addition of elements, and (ii) design procedure: design of the composite solution based on all elements of product superstructure.

Applied numerical examples (composite products, extended composite product, product repair plan, product trajectory) illustrate the proposed approaches.

Note similar type of e-commerce is considered as "designing while shopping" [26]. Generally, our combinatorial synthesis approaches is based on three basic types of combinatorial solving schemes (Table 1):

(1) multiple choice knapsack problem ([11], [15], [29]),

(2) Hierarchical Morphological Multicriteria Design (HMMD) approach (e.g., [19], [20], [21]), and

(3) aggregation procedures [23].

The combinatorial approaches can be considered as a fundamental for two processes: (a) product design (i.e., synthesis, composition, aggregation) and (b) accumulation and representation of customers requirements, preferences, and needs.

A preliminary material of the paper was published as conference paper [22], a simplified example of product aggregation was presented in [23].

II. Structured Model of Product

The following hierarchical multi-layer model "morphological tree" for composite product is examined ([19], [20], [21], [23]) (Fig. 2):

(i) tree-like system model (**T**),

(ii) set of leaf nodes as basic system parts/components (e.g., $\{P_1, ..., P_i, ..., P_m\}$),

(iii) sets of design alternatives (DAs) for each leaf node,

(iv) rankings of DAs (i.e., ordinal priorities) (**R**), and

(v) compatibility estimates between DAs for different leaf nodes (**I**).

This "morphological tree" model is a version of "and-or tree".

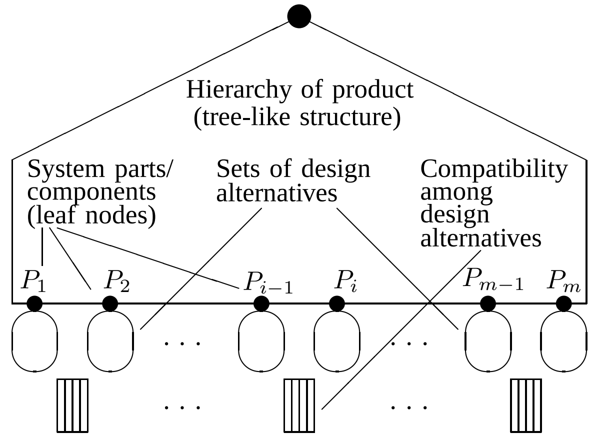

Fig. 2. Architecture of modular product [23]

Further, two simplified illustrative examples of structured models are presented (estimates have only illustrative character). Fig. 3 depicts a three-part motor vehicle (some priorities of DAs are depicted in parentheses, 1 corresponds to the best level): *1.* body A (sedan A_1, universal A_2, jeep A_3, pickup A_4, and sport A_5); *2.* engine B (diesel B_1, gasoline B_2, electric B_3, and hydrogenous B_4); and *3.* equipment C (basic alternative C_1, computer control C_2, and computer control & GPS-linked C_3). Table 2 contains ordinal estimates of compatibility between DAs for different product components which are based on expert judgment (3 corresponds to the best level of compatibility, 0 corresponds to incompatibility).

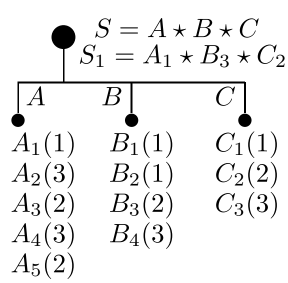

Fig. 3. Motor vehicle

Table 2. Compatibility

	B_1	B_2	B_3	B_4	C_1	C_2	C_3
A_1	3	3	2	1	2	3	2
A_2	3	2	2	2	1	2	3
A_3	3	3	0	0	1	3	3
A_4	2	3	2	2	2	2	3
A_5	3	3	0	0	0	1	3
B_1					3	3	3
B_2					3	3	2
B_3					1	3	3
B_4					0	3	3

Fig. 4 depicts a personal computer (priorities of DAs are depicted in parentheses, 1 corresponds to the best level; here the priorities are based on expert judgment):

0. Notebook S.

1. Hardware $H = B \star U \star V \star J$:

1.1. Mother board B: B_1, B_2;

1.2. CPU U: U_1, U_2, U_3;

1.3. RAM E: E_1, E_2, E_3, E_4;

1.4. Hard drive V: V_1, V_2;

1.5. Video/graphic cards J: J_1, J_2.

2. Software $W = O \star D \star A \star G$:

2.1. Operation system OS O: O_1, O_2, O_3;

2.2. Internet access (browser) A: A_1, A_2, A_3, $A_4 = A_2 \& A_3$;

2.3. Information processing (e.g., engineering software) G: G_1, G_2.

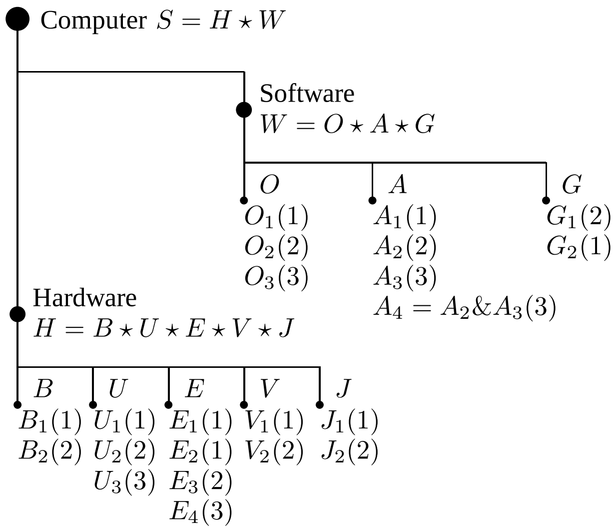

Fig. 4. Personal computer

Table 3 and Table 4 contain ordinal estimates of compatibility between DAs for different product components (3 corresponds to the best level of compatibility, 0 corresponds to incompatibility).

Table 3. Compatibility

	U_1	U_2	U_3	E_1	E_2	E_3	E_4	V_1	V_2	J_1	J_2
B_1	3	2	2	3	3	3	3	3	2	3	2
B_2	2	3	3	2	3	3	3	2	3	2	3
U_1				3	3	3	3	3	3	3	3
U_2				2	3	3	3	3	3	3	3
U_3				2	3	3	3	2	3	2	3
E_1								3	2	3	2
E_2								2	3	2	3
E_3								2	3	2	3
E_4								2	3	2	3
V_1										3	2
V_2										2	3

Table 4. Compatibility

	A_1	A_2	A_3	A_4	G_1	G_2
O_1	3	3	3	3	2	2
O_2	3	3	3	3	3	3
O_3	3	3	3	3	3	3
A_1					3	3
A_2					3	3
A_3					3	3
A_4					3	3

III. Basic Frameworks

A simplified scheme for selection (e.g., search and multi-criteria selection) of a required product is depicted in Fig. 5. Here the product is considered as a whole system.

Recently, many products have a complex configuration and buyer can often generate a product configuration that is more useful for him/her. In Fig. 6, a multi-selection scheme with composition of the resultant composite product from its components is presented.

Further, a multi-selection scheme for selection of structured products and an aggregation of the resultant aggregated product(s) is presented in Fig. 7.

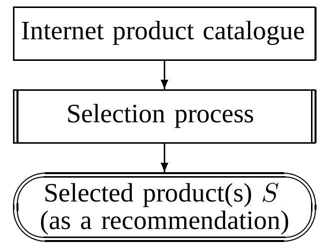

Fig. 5. Selection scheme

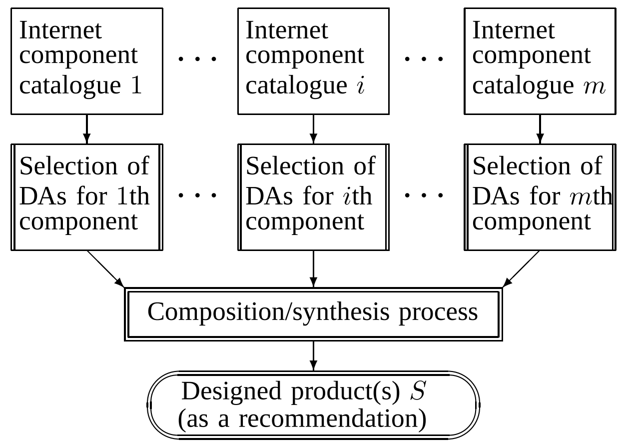

Fig. 6. Multi-selection scheme (composition)

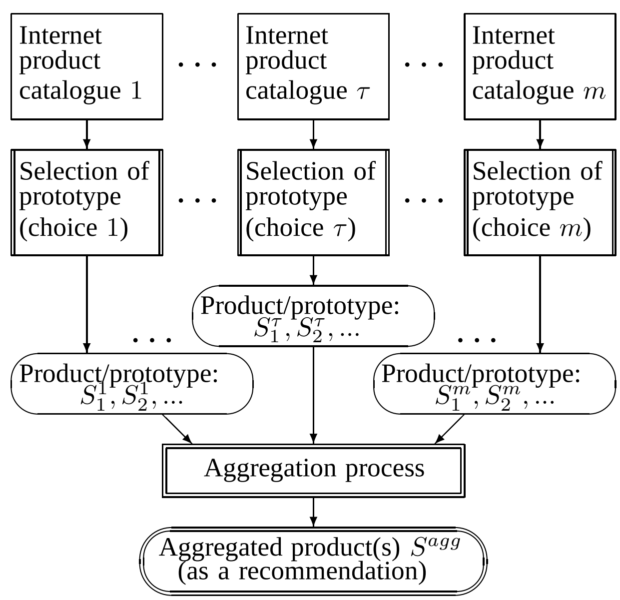

Fig. 7. Multi-selection scheme (aggregation)

Clearly, multi-selection scheme with composition of product from its components and scheme of aggregation of selected modular products can be integrated into a resultant scheme: (i) selection of product components, (ii) synthesis of several modular products/prototypes, and (iii) aggregation of the obtained modular solutions into the aggregated solution.

IV. Underlying Methods

The problem of multicriteria ranking (sorting problem) is the following ([21], [49]). Let $\Psi = \{1, ..., i, ..., p\}$ be a set of items which are evaluated upon criteria $K = \{1, ..., j, ..., d\}$ and $z_{i,j}$ is an estimate (quantitative, ordinal) of item i on criterion j. The matrix $\{z_{i,j}\}$ can be used as a basis to obtain a partial order on Ψ (i.e., the following partition as linear ordered subsets of Ψ):

$$\Psi = \cup_{k=1}^{m} \Psi(k), \ |\Psi(k_1) \cap \Psi(k_2)| = 0 \ \ if \ \ k_1 \neq k_2,$$

$$i_2 \preceq i_1 \ \ \forall i_1 \in \Psi(k_1), \ \forall i_2 \in \Psi(k_2), \ k_1 \leq k_2.$$

Set $\Psi(k)$ is called layer k, and each item $i \in \Psi$ gets priority r_i that equals the number of the corresponding layer. In the paper, an outranking technique is used ([24], [38]).

The basic knapsack problem is (e.g., [11], [15], [29]):

$$\max \sum_{i=1}^{m} c_i x_i \ \ s.t. \sum_{i=1}^{m} a_i x_i \leq b, \ \ x_i \in \{0, 1\}, \ i = \overline{1, m}$$

and additional resource constraints

$$\sum_{i=1}^{m} a_{i,k} x_i \leq b_k; \ k = \overline{1, l};$$

where $x_i = 1$ if item i is selected, for ith item c_i is a value ('utility'), and a_i is a weight (i.e., resource requirement). Often nonnegative coefficients are assumed. In the case of multiple choice problem, the items are divided into groups and it is necessary to select elements (items) or the only one element from each group while taking into account a total resource constraint (or constraints):

$$\max \sum_{i=1}^{m} \sum_{j=1}^{q_i} c_{ij} x_{ij} \ \ s.t. \ \sum_{i=1}^{m} \sum_{j=1}^{q_i} a_{ij} x_{ij} \leq b,$$

$$\sum_{j=1}^{q_i} x_{ij} = 1, \ i = \overline{1, m}; \ \ x_{ij} \in \{0, 1\}.$$

The knapsack-like problems above are NP-hard and can be solved by the following approaches ([11], [29]): (i) enumerative methods (e.g., Branch-and-Bound, dynamic programming), (ii) fully polynomial approximate schemes, and (iii) heuristics (e.g., greedy algorithms). In the paper, a greedy algorithm is used.

Further, Hierarchical Morphological Multicriteria Design (HMMD) approach based on morphological clique problem is briefly described ([19], [20], [21]). A examined composite (modular, decomposable) system consists of components and their interconnection or compatibility (**I**). Basic assumptions of HMMD are the following: *(a)* a tree-like structure of the system; *(b)* a composite estimate for system quality that integrates components (subsystems, parts) qualities and qualities of IC (compatibility) across subsystems; *(c)* monotonic criteria for the system and its components; *(d)* quality of system components and **I** are evaluated on the basis of coordinated ordinal scales. The designations are: (1) design alternatives (DAs) for leaf nodes of the model; (2) priorities of DAs ($r = \overline{1, k}$; 1 corresponds to the best one); (3) ordinal compatibility (**I**) for each pair of DAs ($w = \overline{1, l}$; l corresponds to the best one). The basic phases of HMMD are: *1.* design of the tree-like system model; *2.* generation of DAs for leaf nodes of the model; *3.* hierarchical selection and composing of DAs into composite DAs for the corresponding higher level of the system hierarchy; *4.* analysis and improvement of composite DAs (decisions).

Let S be a system consisting of m parts (components): $P(1), ..., P(i), ..., P(m)$. A set of design alternatives is generated for each system part above. The problem is:

Find a composite design alternative $S = S(1) \star ... \star S(i) \star ... \star S(m)$ *of DAs (one representative design alternative* $S(i)$ *for each system component/part* $P(i)$, $i = \overline{1, m}$ *) with nonzero* **I** *between design alternatives.*

A discrete space of the system excellence on the basis of the following vector is used: $N(S) = (w(S); n(S))$, where $w(S)$ is the minimum of pairwise compatibility between DAs which correspond to different system components (i.e., $\forall \ P_{j_1}$ and P_{j_2}, $1 \leq j_1 \neq j_2 \leq m$) in S, $n(S) = (n_1, ..., n_r, ...n_k)$, where n_r is the number of DAs of the rth quality in S.

As a result, we search for composite decisions which are nondominated by $N(S)$ (i.e., Pareto-efficient solutions). The considered combinatorial problem is NP-hard and an enumerative scheme is used. Fig. 8 and Fig. 9 illustrate the composition problem by a numerical example (estimates of compatibility are pointed out in Fig. 9). In the example, composite DA is: $S_1 = X_2 \star Y_1 \star Z_2$, $N(S_1) = (2; 2, 0, 1)$.

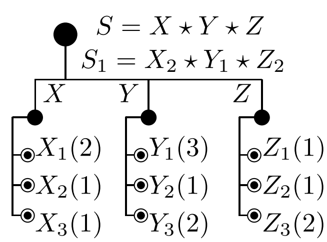

Fig. 8. Composition

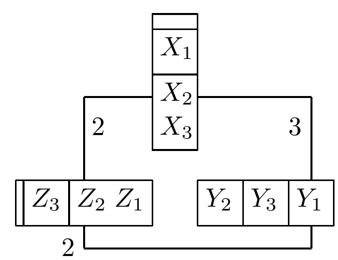

Fig. 9. Concentric presentation

Aggregation of composite products (as modular solutions) can be considered as follows [23]. Fig. 10 illustrates substructure, superstructure and "kernel" (as a part of substructure) for three initial solutions S^1, S^2, and S^3.

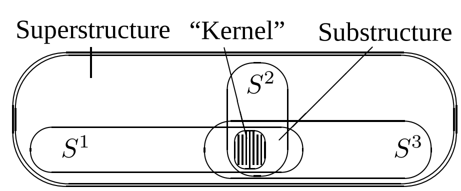

Fig. 10. Substructure and superstructure

In [23], basic aggregation strategies are described, for example:

1. *Extension strategy*: *1.1.* building a "kernel" for initial solutions (i.e., substrcuture/subsolution or an extended subsolution), *1.2.* generation of a set of additional solution elements, *1.3.* selection of additional elements from the generated set while taking into account their "profit" and resource requirements (i.e., a total "profit" and total resource constrain) (here knapsack-like problem is used).

2. *Compression strategy*: *2.1.* building a supersolution (as

a superstructure), *2.2.* generation of a set of solution elements from the built supersolution as candidates for deletion, *2.3.* selection of the elements-candidates for deletion while taking into account their "profit" and resource requirements (i.e., a total profit and total resource constrain) (here knapsack-like problem with minimization of objective function is used).

Note, a general aggregation strategy has to be based on searching for a consensus/median solution S^M ("generalized" median) for the initial solutions $\overline{S} = \{S^1, ..., S^n\}$ (e.g., [23]):

$$S^M = \arg\ min_{X \in \overline{S}}\ (\sum_{i=1}^{n}\ \rho(X, S^i)),$$

where $\rho(X, Y)$ is a proximity (e.g., distance) between two solutions X and Y. Mainly, searching for the median for many structures is usually NP complete problem. In our case, product structures correspond to a combination of tree, set of DAs, their estimates, matrices of compatibility estimates. As a result, the proximity between the structures are more complicated and the "generalized" median problem is very complex. Thus, simplified (approximate) solving strategies are often examined, for example [23]: (a) searching for "set median" (i.e., one of the initial solutions is selected), (b) "extension strategy" above, (c) "compression strategy" above.

3. *New design strategy*: *3.1.* building a supersolution (as a superstructure) and design, *3.2.* generation of a "design space" (as a product structure and design elements), *3.3.* design of the composite solution over the obtained design element (here multiple choice problem or hierarchical morphological design approach can be used).

V. Examples

A. Multicriteria Ranking/Selection

Multicriteria comparison/selection of product is the basic problem in multicriteria decision making. Table 5 contains an illustrative comparison example for five products, used criteria are (here ordinal scale is $[1, 5]$, $-$ corresponds to the case when minimum estimate is the best, $+$ corresponds to the case when maximum estimate is the best): cost $K_1, -$, reliability $K_2, +$, maintenance-ability K_3+, upgrade-ability K_3+. Evidently, two alternatives (products) A_1 and A_4 are Pareto-efficient solutions (corresponding priority equals 1), alternative A_2 is dominated by all others (priority equals 3), and two alternatives A_3 and A_5 are intermediate by their quality (priority equals 2).

Table 5. Estimates

DAs	Criteria				Priority r_i
	1	2	3	4	
A_1 (computer 1)	2	4	5	4	1
A_2 (computer 2)	3	2	1	2	3
A_3 (computer 3)	2	4	3	3	2
A_4 (computer 4)	1	5	4	5	1
A_5 (computer 5)	3	3	4	4	2

B. Synthesis of Composite Product

Here a numerical example of combinatorial synthesis (morphological design) of a composite product for the simplified example of three part motor vehicle is considered (Fig. 3, Table 2). This example corresponds to implementation of multi-selection scheme for composition of product components (Fig. 6). The obtained Pareto-efficient solutions are the following (Fig. 11):

$S_1 = A_1 \star B_1 \star C_2,\ N(S_1) = (3; 2, 1, 0)$;
$S_2 = A_1 \star B_1 \star C_1,\ N(S_2) = (2; 3, 0, 0)$.

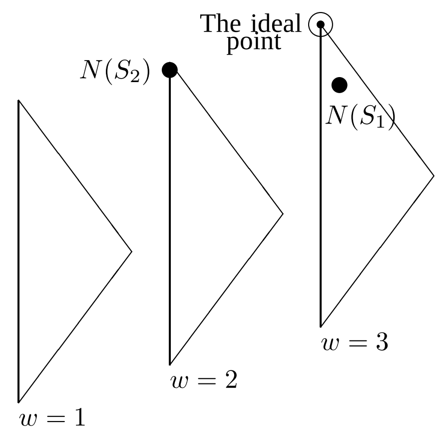

Fig. 11. Space of system quality

C. Synthesis of Extended Composite Product [22]

Now an extended composite product in electronic shopping is examined including the composite product, way of payment, place of purchase, etc. The simplified structure of the extended composite product (*buying a motor vehicle*) is depicted in Fig. 12: *1.* origin of a motor vehicle A (domestic A_1 foreign A_2); *2.* configuration of a motor vehicle B (minimal B_1 and maximal B_2); *3.* way of payment C (credit C_1, cash C_2, and hire-purchase C_3); *4.* place of purchase D (motor vehicle store D_1, motor vehicles dealer D_2, and directly from manufacturer D_3); and *5.* level of amortization E (new E_1, used E_2).

The following criteria are used ('+' corresponds to positive orientation of an ordinal scale as $[1, 5]$ and '-' corresponds to the negative orientation of the scale): *(a)* cost K_{a1} (-), brand prestigiousness K_{a2} (+), useful life K_{a3} (+), need of maintenance K_{a4} (-), reliability K_{a5} (+); *(b)* cost K_{b1} (-), brand prestigiousness K_{b2} (+), upgradeability K_{b3} (+); *(c)* credit risk K_{c1} (-), cost of usage K_{c2} (+), availability K_{c3} (+); *(d)* reliability K_{d1} (-), cost K_{d2} (+), service quality K_{d3} (+), warranty K_{d4} (-); and *(e)* cost K_{e1} (-), need of maintenance K_{e2} (+), warranty K_{e3} (+).

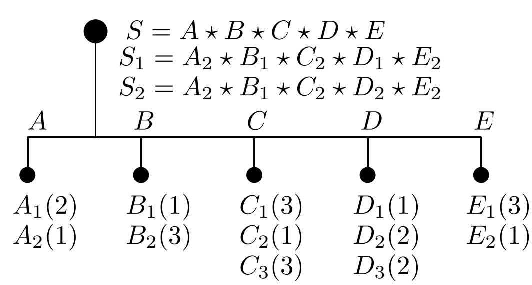

Fig. 12. Structure of extended product

Tables 6, 7, 8, 9, and 10 contain ordinal estimates of DAs upon the above-mentioned criteria (expert judgment). Estimates of compatibility between DAs are contained in Table 11 (scale $[0,3]$, expert judgment).

Table 6. Estimates

DAs	Criteria 1	2	3	4	5
A_1	2	3	3	3	2
A_2	4	5	5	5	4

Table 7. Estimates

DAs	Criteria 1	2	3
B_1	2	3	5
B_2	4	5	2

Table 8. Estimates

DAs	Criteria 1	2	3
C_1	5	5	4
C_2	1	4	3
C_3	5	3	4

Table 9. Estimates

DAs	Criteria 1	2	3	4
D_1	4	4	4	5
D_2	2	3	2	2
D_3	3	3	1	2

Table 10. Estimates

DAs	Criteria 1	2	3
E_2	4	2	5
E_1	2	4	1

Table 11. Compatibility

	B_1	B_2	C_1	C_2	C_3	D_1	D_2	D_3	E_1	E_2
A_1	3	3	2	3	2	3	3	0	3	3
A_2	3	3	3	3	3	3	3	2	3	3
B_1			3	3	3	3	3	2	3	3
B_2			3	3	3	3	2	1	3	2
C_1						3	1	0	3	1
C_2						3	3	2	3	3
C_3						2	0	0	3	0
D_1									3	1
D_2									2	3
D_3									1	3

The resultant priorities of DAs are obtained on the basis of multicriteria ranking for each system part (scale $[1,3]$). The priorities are shown in Fig. 12 in parentheses.

The resultant composite Pareto-efficient DAs are the following (Fig. 13):

$S_1 = A_2 \star B_1 \star C_2 \star D_1 \star E_2$, $N(S_1) = (1; 5, 0, 0)$ and

$S_2 = A_2 \star B_1 \star C_2 \star D_2 \star E_2$, $N(S_2) = (3; 4, 1, 0)$.

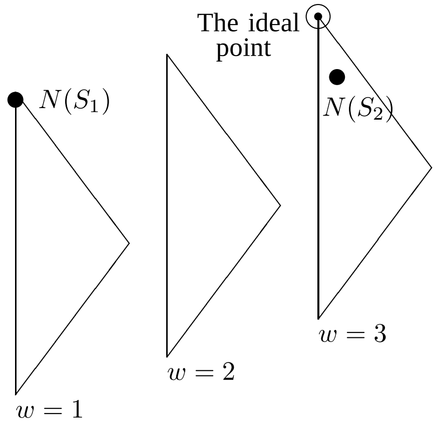

Fig. 13. Space of system quality

D. Synthesis of Product Repair Plan [22]

For complex products it is often necessary to consider repair plans. The described example corresponds to a car. Generally, the car repair plan consists of the following parts: (1) payment, (2) body, (3) electric & electronic subsystem, and (4) tuning, and (5) motor vehicle. Here a compressed plan is examined as follows (Fig. 14) (priorities of DAs are based on expert judgment and shown in parentheses):

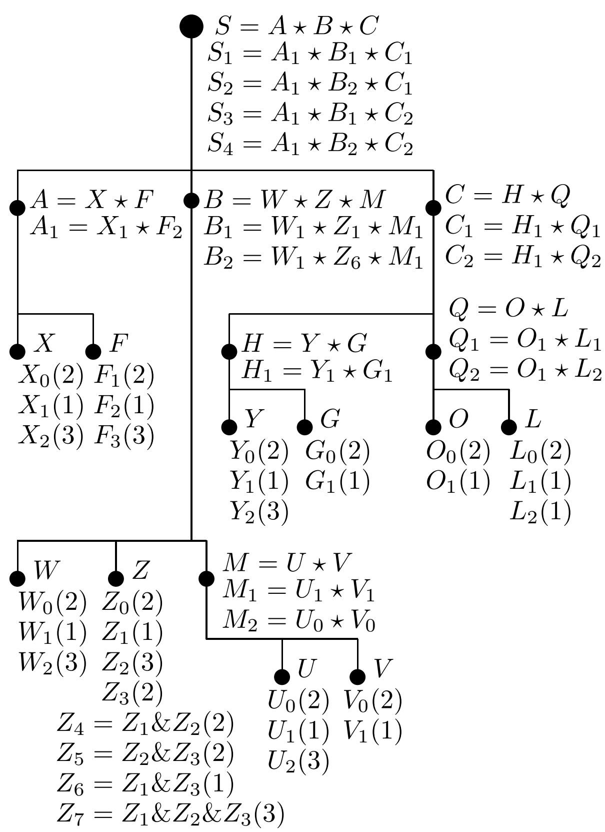

Fig. 14. Structure of repair plan

0. Plan $S = A \star B \star C$

1. Payment $A = X \star F$

1.1. payment scheme X: 100 % payment X_0, prepayment of 50...80 percent for parts X_1; bank loan X_2;

1.2. version F: cash F_1, credit card F_2, bank transfer F_3.

2. Body $B = R \star Z \star M$:

2.1. frame W: None W_0, technical diagnostics W_1, follow-up assembly W_2;

2.2. hardware Z: None Z_0, replacement of defect parts Z_1, repair of body-defects Z_2, fitting Z_3, $Z_4 = Z_1\&Z_2$, $Z_5 = Z_1\&Z_3$, $Z_6 = Z_2\&Z_3$, $Z_7 = Z_1\&Z_2\&Z_3$;

2.3. finishing $M = U \star V$:

2.3.1. painting U: None U_0, partial painting U_1, painting U_2;

2.3.2. appearance restoration V: None V_0, Yes V_1.

3. Electric & electronic subsystem $C = H \star Q$:

3.1. Computer & navigation subsystem $H = Y \star G$:

3.1.1. Computer Y: None Y_0, upgrade Y_1, additional or new computer Y_2;

3.1.2. system GPS G: None G_0, GPS system G_1;

3.2. wiring & lighting $Q = O \star L$:

3.2.1. wiring O: None O_0, repair O_1;

3.2.2. lighting L: None L_0, partial replacement L_1, replacement L_2.

Tables 12 and 13 contain estimates of compatibility (expert judgment).

Table 12. Compatibility

	M_1	M_2	W_0	W_1	W_2
Z_0	2	3	3	3	0
Z_1	3	2	2	3	3
Z_2	3	2	0	3	3
Z_3	3	2	0	2	3
Z_4	3	2	2	3	3
Z_5	3	2	0	3	3
Z_6	3	2	2	3	3
Z_7	3	2	2	3	3
M_1			0	3	3
M_2			3	2	2

	L_0	L_1	L_2
O_0	3	2	2
O_1	1	3	3

	F_1	F_2	F_3
X_1	3	3	3
X_2	3	3	3
X_3	0	3	2

Table 13. Compatibility

	G_0	G_1
Y_0	3	0
Y_1	2	3
Y_2	1	2

	V_0	V_1
U_0	3	0
U_1	0	2
U_2	0	3

The following intermediate composite Pareto-efficient DAs are obtained:

$A_1 = X_1 \star F_2$, $N(A_1) = (3; 2, 0, 0)$;

$H_1 = Y_1 \star G_1$, $N(H_1) = (3; 2, 0, 0)$;

$Q_1 = O_1 \star L_1$, $N(Q_1) = (3; 2, 0, 0)$; $Q_2 = O_1 \star L_2$, $N(Q_2) = (3; 2, 0, 0)$;

$M_1 = U_1 \star V_2$, $N(M_1) = (2; 2, 0, 0)$; $M_2 = U_0 \star V_0$, $N(M_2) = (3; 0, 2, 0)$;

$B_1 = W_1 \star Z_1 \star M_1$, $N(B_1) = (3; 3, 0, 0)$; $B_2 = W_1 \star Z_6 \star M_1$, $N(B_2) = (3; 3, 0, 0)$.

The resultant composite Pareto-efficient DAs are the following (for a final user's analysis/choice): $S_1 = A_1 \star B_1 \star C_1$, $S_2 = A_1 \star B_2 \star C_1$, $S_3 = A_1 \star B_1 \star C_2$, and $S_4 = A_1 \star B_2 \star C_2$.

E. Synthesis of Product Trajectory

In addition, it is reasonable to consider the design problem for synthesis of product (system) trajectory as follows (e.g., [21]):

Combine a trajectory (i.e., selection of a system solution at each time stage) while taking into account quality of composite DAs at each time stage and a cost of the component changes.

Let us consider a three-stage example: (i) computer for stage 1 (Fig. 4), (ii) computer for stage 1 (Fig. 15), and (iii) computer for stage 1 (Fig. 16). Here the tree-like structure and DAs are the same, priorities of DAs are different (priorities are shown in parentheses in Fig. 4, Fig. 15, Fig. 16), estimates of compatibility between DAs are the same (Table 3) (estimates have an illustrative character and are based on expert judgment).

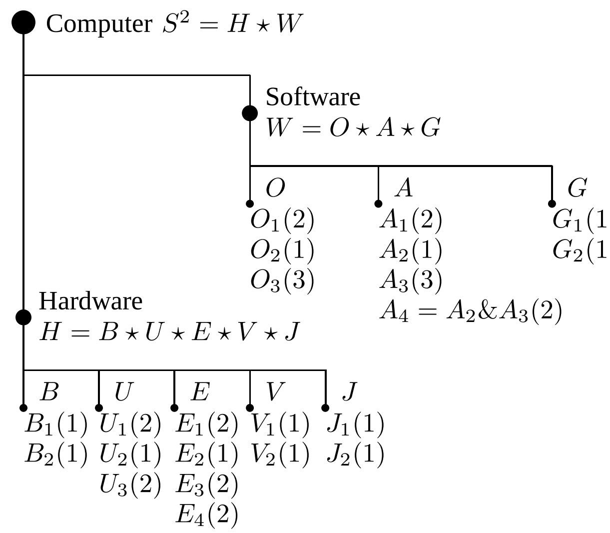

Fig. 15. Personal computer (stage 2)

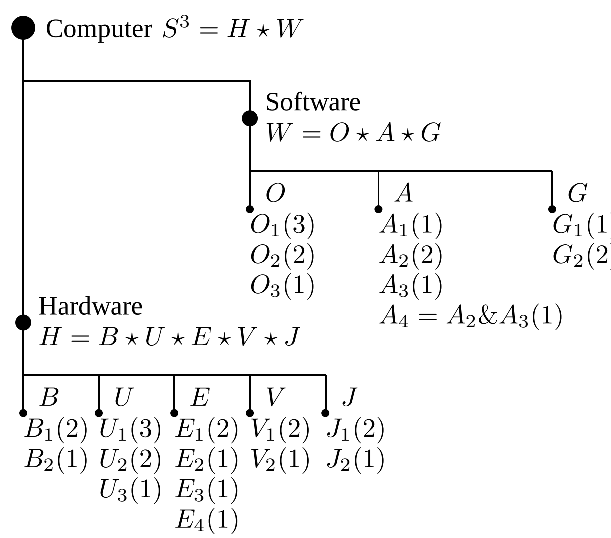

Fig. 16. Personal computer (stage 3)

The following composite solutions are obtained (Fig. 4, Fig. 15, Fig. 16):

Stage 1:

$H_1 = B_1 \star U_1 \star E_1 \star V_1 \star J_1$, $N(H_1) = (3; 5, 0, 0)$,

$W_1 = O_1 \star A_1 \star G_2,\ N(W_1) = (2; 3, 0, 0),$
$W_2 = O_2 \star A_1 \star G_2,\ N(W_2) = (3; 2, 1, 0);$
$S_1 = H_1 \star W_1 = (B_1 \star U_1 \star E_1 \star V_1 \star J_1) \star (O_1 \star A_1 \star G_2),$
$S_2 = H_1 \star W_2 = (B_1 \star U_1 \star E_1 \star V_1 \star J_1) \star (O_2 \star A_1 \star G_2).$
Stage 2:
$H_1^2 = B_2 \star U_2 \star E_2 \star V_2 \star J_2,\ N(H_1^2) = (3; 5, 0, 0),$
$W_1^2 = O_2 \star A_2 \star G_1,\ N(W_1^2) = (3; 3, 0, 0),$
$W_2^2 = O_2 \star A_2 \star G_2,\ N(W_2^2) = (3; 3, 0, 0);$
$S_1^2 = H_1^2 \star W_1^2 = (B_2 \star U_2 \star E_2 \star V_2 \star J_2) \star (O_2 \star A_2 \star G_1),$
$S_2^2 = H_1^2 \star W_2^2 = (B_2 \star U_2 \star E_2 \star V_2 \star J_2) \star (O_2 \star A_2 \star G_2).$
Stage 3:
$H_1^3 = B_2 \star U_3 \star E_2 \star V_2 \star J_2,\ N(H_1^3) = (3; 5, 0, 0),$
$W_1^3 = O_3 \star A_1 \star G_1,\ N(W_1^3) = (2; 3, 0, 0),$
$W_2^3 = O_3 \star A_3 \star G_1,\ N(W_2^3) = (3; 2, 1, 0);$
$S_1^3 = H_1^3 \star W_1^3 = (B_2 \star U_3 \star E_2 \star V_2 \star J_2) \star (O_3 \star A_1 \star G_1),$
$S_2^3 = H_1^3 \star W_2^3 = (B_2 \star U_3 \star E_2 \star V_2 \star J_2) \star (O_3 \star A_3 \star G_1).$

Table 14 contains the numbers of element changes for products at different stages (products at neighborhood stages are compared): $\delta(S_1, S_1^2)$, etc. The estimate of compatibility is computed as follows (Table 15): $\xi(S_1, S_1^2) = (8 - \delta(S_1, S_1^2))$.

Table 14. Changes $\delta(S', S'')$

	S_1^2	S_2^2	S_1^3	S_2^3
S_1	8	7	$-$	$-$
S_2	7	6	$-$	$-$
S_1^2			3	3
S_2^2			3	4

Table 15. Compatibility

	S_1^2	S_2^2	S_1^3	S_2^3
S_1	0	1	$-$	$-$
S_2	1	2	$-$	$-$
S_1^2			5	5
S_2^2			5	4

The designed trajectory is based on combinatorial synthesis. It is assumed, the composite solutions for stages 1, 2, and 3 (i.e., S_1, S_2, S_1^2, S_2^2, S_1^3, S_2^3) have priorities at the level 1. The best composition (while taking into account compatibility estimates) is (Fig. 17): $\overline{\alpha} =< S_2, S_2^2, S_1^3 >$,

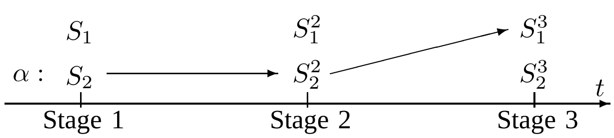

Fig. 17. Design of system trajectory

F. Aggregation of Modular Products

An example of aggregation process is based on the multi-choice scheme with aggregation (Fig. 7). An initial morphological structure of a car is the following (Fig. 18) (in real application, this structure can be considered as a result of processing the selected products/solutions) [23]:

0. Car $S = A \star B \star C$.

1. Main part $A = E \star D$:

1.1. Engine E: diesel E_1, gasoline E_2, electric E_3, hydrogenous E_4, and hybrid synergy drive HSD E_5;

1.2. Body D: sedan D_1, universal D_2, jeep D_3, pickup D_4, and sport D_5.

2. Mechanical part $B = X \star Y \star Z$:

2.1. gear box X: automate X_1, manual X_2;

2.2. suspension Y: pneumatic Y_1, hydraulic Y_2, and pneumohydraulic Y_3;

2.3. drive Z: front-wheel drive Z_1, rear-drive Z_2, all-wheel-drive Z_3.

3. Safety part $C = O \star G$:

3.1. O: "absence" O_0, electronic O_1;

3.2. Safety subsystem G: "absence" G_0, passive G_1, active G_2.

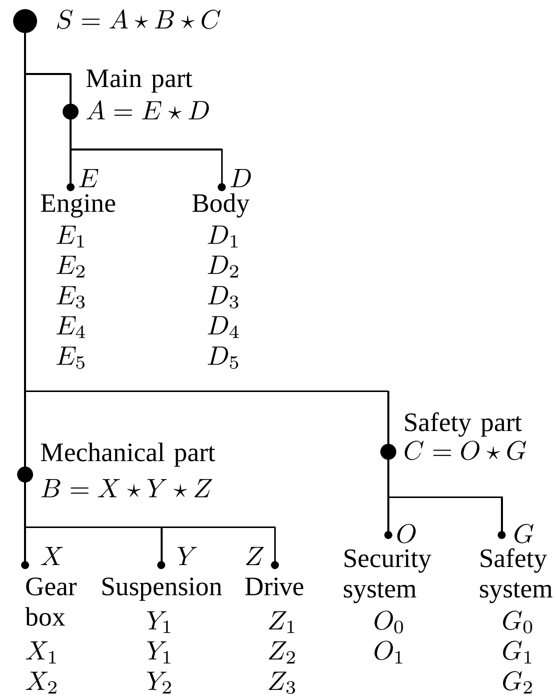

Fig. 18. General structure of car

The following initial solutions/prototypes are considered [23]:

$S_1^1 = E_1 \star D_1 \star X_1 \star Y_1 \star Z_1 \star O_1 \star G_1,$

$S_2^1 = E_5 \star D_1 \star X_1 \star Y_1 \star Z_1 \star O_1 \star G_2,$

$S_1^2 = E_2 \star D_1 \star X_2 \star Y_1 \star Z_1 \star O_0 \star G_1,$

$S_1^3 = E_2 \star D_3 \star X_1 \star Y_2 \star Z_3 \star O_1 \star G_0$, and

$S_2^3 = E_2 \star D_5 \star X_1 \star Y_3 \star Z_1 \star O_1 \star G_1.$

The substructure of the five solutions above is empty. A "kernel" can be designed by the following element inclusion rule:

component ι *is included into the "kernel" if* $\eta_\iota \geq \lambda$,

where η_ι is the number of DAs ι in initial prototypes/products, $\lambda \leq m$, m is the number of initial prototypes/product. The obtained "kernel" (as a basis for extension) is presented in Fig. 19 (here $\lambda = 2$). The superstructure is presented in Fig. 20.

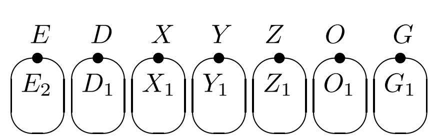

Fig. 19. "System kernel"

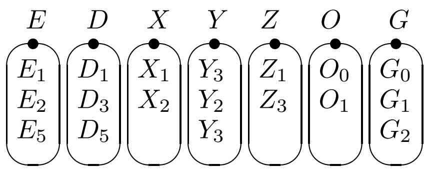

Fig. 20. Superstructure of solutions

The extension procedure is the following. Table 16 contains addition operations and their estimates (scales $[1, 3]$, expert judgment).

Table 16. Addition operations

i	Operation	Binary variable	Cost a_i	Profit c_i
1	$E_2 \Rightarrow E_5$	x_1	3	3
2	$Y_1 \Rightarrow Y_3$	x_2	1	3
3	$Z_1 \Rightarrow Z_3$	x_2	2	1
4	$G_1 \Rightarrow G_2$	x_4	2	3

The addition problem (simplified knapsack problem) is:

$$\max \sum_{i=1}^{4} c_i x_i \quad s.t. \sum_{i=1}^{4} \ a_i x_i \le b, \quad x_i \in \{0, 1\}.$$

Examples of the obtained resultant aggregated solutions are (a simple greedy algorithm was used; the algorithm is based on ordering of elements by c_i/a_i):

(1) $b_1 = 5$: $(x_1 = 0,\ x_2 = 1,\ x_3 = 1,\ x_4 = 1)$,
$S'_{b_1} = E_2 \star D_1 \star X_1 \star Y_3 \star Z_3 \star O_1 \star G_1$;
(2) $b_2 = 6$: $(x_1 = 1,\ x_2 = 1,\ x_3 = 0,\ x_4 = 1)$,
$S'_{b_2} = E_5 \star D_1 \star X_1 \star Y_3 \star Z_1 \star O_1 \star G_2$.

The procedure of new design is the following. Table 17 contains design alternatives and their estimates (scales $[1, 5]$, expert judgment). The design alternatives correspond to superstructure (Fig. 20).

Table 17. Design alternatives

κ	Design alternative	Binary variable	Cost a_{ij}	Profit c_{ij}
1	E_1	x_{11}	3	3
2	E_2	x_{12}	3	4
3	E_5	x_{13}	4	5
4	D_1	x_{21}	2	2
5	D_3	x_{22}	3	3
6	D_5	x_{23}	5	4
7	X_1	x_{31}	3	4
8	X_2	x_{32}	2	3
9	Y_1	x_{41}	2	2
10	Y_2	x_{42}	2	3
11	Y_3	x_{43}	3	4
12	Z_1	x_{51}	1	1
13	Z_3	x_{52}	2	2
14	O_0	x_{61}	1	1
15	O_1	x_{62}	2	3
16	G_0	x_{71}	1	1
17	G_1	x_{72}	2	3
18	G_2	x_{73}	2	4

It is assumed design alternatives for different product components are compatible. Thus, multiple choice problem for the new design is used:

$$\max \sum_{i=1}^{7} \sum_{j=1}^{q_i} c_{ij} x_{ij} \quad s.t. \ \sum_{i=1}^{7} \sum_{j=1}^{q_i} a_{ij} x_{ij} \le b,$$

$$\sum_{j=1}^{q_i} x_{ij} = 1 \ \ \forall i = \overline{1, 7}, \quad x_{ij} \in \{0, 1\}.$$

Clearly, $q_1 = 3$, $q_2 = 3$, $q_3 = 2$, $q_4 = 3$, $q_5 = 2$, $q_6 = 2$, $q_7 = 3$. Examples of the obtained resultant aggregated solutions are (a simple greedy algorithm was used; the algorithm is based on ordering of elements by c_i/a_i):

(1) $b^1 = 14$: $(x_{12} = 1, x_{21} = 1, x_{32} = 1, x_{42} = 1, x_{51} = 1, x_{62} = 1,\ x_{73} = 1)$, $S''_{b^1} = E_2 \star D_1 \star X_2 \star Y_2 \star Z_1 \star O_1 \star G_2$;

(2) $b^2 = 17$: $(x_{13} = 1, x_{22} = 1, x_{31} = 1, x_{41} = 1, x_{52} = 1, x_{62} = 1,\ x_{73} = 1)$, $S''_{b^2} = E_5 \star D_3 \star X_1 \star Y_3 \star Z_3 \star O_1 \star G_2$.

VI. Conclusion

In the paper, prospective frameworks for electronic shopping of modular products are suggested and examined (selection, composition/synthesis, aggregation). A special composite hierarchical structure for modular products is used: tree-like system model, design alternatives for product components, priorities of the design alternatives, estimates of compatibility between design alternatives. Solving procedures are based on combinatorial solving frameworks (multicriteria ranking, knapsack-like problems, hierarchical morphological design, aggregation). The suggested approaches have been illustrated by simplified applied realistic examples.

In the future, it may be reasonable to consider the following research directions:

1. investigation of other applications;

2. taking into account user's/customer's profiles;

3. usage of multicriteria knapsack problem and multicriteria multiple choice problem;

4. examination of various kinds of proximity between composite products;

5. consideration of support tools to design product structures; and

6. usage of fuzzy set approaches and AI techniques in the examined product design problems.

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